

Research Article

Applying landscape ecological principles in comprehensive landscape protection: Šumava National Park as a case study

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Abstract

In the face of ongoing anthropogenic pressure and biodiversity loss, there is a need to protect nature more effectively. Therefore, we propose a comprehensive and consecutive approach utilising landscape ecological principles and methods for effective landscape protection and spatial nature conservation. Methods applicable in various conditions are exemplified through case studies from the Šumava National Park, the largest NP in Czechia. Using a set of spatial environmental, landscape ecological and geographical data we can:

- 1) Characterise the area of interest from the physical-geographical, socioeconomic, and management point of view to create the concept's framework and review important background information for analysis of the area. Therefore, the key factors for landscape protection and biodiversity conservation are defined.
- 2) Analyse trends and processes of landscape dynamics in terms of land cover, landscape structure and habitat fragmentation and connectivity, which helps us to set main objectives of landscape protection and nature conservation.
- 3) Use data about environment conditions and key species and habitat occurrence to model habitat suitability, identify their suitable areas, and thus improve their protection. As a result, areas of high conservation value are distinguished.
- 4) Synthetize outputs of the above-mentioned steps and prioritise the target goals of landscape protection and biodiversity conservation in the area of interest. This leads to the effective zonation, which is a necessary condition for the application of appropriate management measures.

Key words: Conservation planning, landscape ecology, nature conservation

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Introduction

Territorial nature protection is a well-known and widely used approach to preserve landscape and biodiversity (Antrop 2005). The most common tool of landscape protection is establishing a network of protected areas (PAs). In recent decades, PAs total extent has expanded greatly around the world (Watson

et al. 2014). Despite the enlargement of PAs territories, it has not met the target of 17% of land and inland waters protected by 2020 (Aichi Target 11). Moreover, Kunming-Montreal Global Biodiversity Framework has targets for 2030 as to plan and manage areas to reduce biodiversity loss and to conserve 30% of the Earth. Furthermore, the current PAs set is not representative; not all ecoregions and endangered species are protected sufficiently (Maxwell et al. 2020). This is because the establishment of PAs and their management decisions are rather driven by political, economic, and other interests than scientific knowledge (Müller and Opgenoorth 2014). Therefore, it is complicated to design reserves with regard to all natural values and processes and allow coexistence of conservation targets with other activities within the area to delimit appropriate land-use management (Bengtsson et al. 2003; Bekessy et al. 2012).

PAs are recognized as the best tool to preserve endangered species populations and their habitats; more generally, biodiversity, and ecological functions of the area (Watson et al. 2014). Furthermore, PAs also mitigate the negative effects of the development of human society, such as built-up areas or unsuitable land use and land cover changes (Martin-López et al. 2011; Sharafi et al. 2012; Montesino Pouzols et al. 2014; Ceaşu et al. 2015; Fuente et al. 2020).

The oldest PAs have protected mainly iconic species and landscapes (Martín-López et al. 2011); later, biodiversity and ecosystem services became the subjects and, more recently, also human activities such as tourism and sustainability of local communities with social and economic aims are also included as parts of the mission of PAs (Moilanen et al. 2011; Watson et al. 2014). These wider objectives and diversification of PA aims can create conflicts of different interests and priorities within some PAs (Soliku and Schraml 2018). There is a general assumption that human activities in PAs should be restricted or regulated by law to maintain nature quality (Bengtsson et al. 2003). However, various visions of the PAs' future including large human exploitation are often proposed and even applied, while appropriate data and relevant negotiation are lacking (e.g., Yakusheva 2019).

Yellowstone National Park, the first national park in the world, was founded in 1872. Roughly, one hundred years later the number and area of PAs started to grow quickly as a response to degradation of the environment (Watson et al. 2014). In Central Europe, a region with a long-term anthropogenic presence, the first PAs were already established in the 1820s (Ceaşu et al. 2015; Hausner et al. 2015). The first nature reserves in Czechia were established in 1838 (Čihař 1997) and, nowadays, the number and area of PAs are increasing in Czechia as well (Pelc 2018). However, ensuring effective nature protection and long-term stability in the management of protected areas is a big challenge for Czechia as well as other countries, where distrust of local actors and lack of communication between local communities and conservation authorities are common (Yakusheva 2019). There is an evident problem especially in post-communist Eastern Europe; priorities of nature conservation are not commonly agreed on and in the hunt for economic development, the preservation of biodiversity is put to one side (Kindlmann and Křenová 2016).

Therefore, facing biodiversity loss and ongoing anthropogenic pressure, the effective prioritisation of conservation goals in naturally valuable areas, as well as the delimitation of PAs and their zonation and management, are crucial tasks for contemporary nature conservation. In the context of the above-mentioned

problems, we are persuaded that the general approach and methods presented within this paper can help to bridge the gaps and help to manage PAs more properly. In this paper, we propose adopting methods of geography and landscape ecology for effective nature conservation planning and appropriate management of PAs. We stressed issues of delimiting the PAs, integrating biodiversity and natural processes and dealing with spatial features affecting the management of PAs.

Our aim is to bridge the gap of various approaches dealing with conservation planning and prioritisation with easy, innovative and objective data-driven four-steps methods especially based on landscape ecology approaches using appropriate data and tools. We considered dilemmas of social-ecological systems (Soliku and Schraml 2018; Yakusheva 2019), conservation based on species or ecosystems methodology (Mace et al. 2007; Ceașu et al. 2015) and tried to plan systematically and evidence-based (Margules and Pressey 2000; Sutherland et al. 2004).

Landscape ecology deals with space and its development, dynamics, patterns, and how all these aspects together influence relationships between natural elements (energy, material, species). Furthermore, landscape ecology is a science on the edge of several scientific disciplines, from which ecology and geography are the nearest ones (Turner 1989; Turner 2005; Cushman et al. 2008). Landscape ecology connects the landscape scale with ecological processes (Tscharntke et al. 2012). It implies that landscape ecology brings interesting and very useful information for land-use planning, spatial landscape protection, and nature conservation (Turner 1989). Effective protection of natural processes, ecosystem quality, and diversity, which is now in high demand, can also benefit from landscape ecology knowledge because anthropogenic pressure brings habitat loss, fragmentation, and land-use intensification, and also causes subsequent biodiversity loss (Martin-López et al. 2011; Sharafi et al. 2012). Therefore, in this article, we review landscape ecological principles and indicate the most effective of them for improving the state of PAs.

In this paper, we use our large experience and results of long-term research conducted in Šumava National Park (**ŠNP**), Czechia, to introduce this new **LEP** (landscape ecological principles) approach and discuss opportunities, challenges, and potential of its use in a common overview.

Methods

Landscape ecological principles

Landscape ecological principle) are defined here in accordance with three main aims on landscape ecological studies (*in sensu* Forman and Godron 1986): (i) landscape structure, (ii) changes of land cover, and (iii) functions of landscape. We used LEP in a four-step approach. Landscape function was especially assessed in the first step investigating abiotic and socio-economic conditions of the area. Land cover changes were analysed in the second step and landscape structure is crucial for the second and third step as well. Finally, all these steps were integrated into the fourth step, creating a proposal for territorial nature conservation priorities. The individual steps are described below as (also in Fig. 1, Table 1):

1. Summarising conditions of a study area from natural, socio-economic and management points of view;
 - a. Characterization of the study area based on landscape or physical-geographical typology (Chuman and Romportl 2010; Romportl et al. 2013; Janík and Romportl 2016). This also serves as a framework for further analysis.
 - b. Mapping of human activities and management in the area (Brandon and Wells 1992; Mayer and Job 2008; Brown et al. 2015; Janík and Romportl 2017; Janík 2020).
2. Based on summarised conditions, landscape dynamics driven by rather human (Kupková et al. 2013; Janík et al. 2019; Janík et al. 2022) or rather natural processes (Turner 1989; Janík and Romportl 2018) on various scales were analysed. Broader context to highlight main trends, values, problems and differences, which are important for protection and management of the area, were included. By a synthesis of knowledge derived from step 1 and step 2, it is possible to evaluate landscape dynamics according to different existing management (e.g., ownership; Křenová et al. 2022).
3. Capacity for harbouring and enhancing species was assessed - habitats and species occurrence, habitat requirements of target species, and suitable habitat capacities of a study area were analysed (Janík et al. 2021b).
4. The last step is the integration of the previous ones. It shows landscape ecology in practice as a synthesis of knowledge about landscape and its values. Objective data about habitats and key species occurrence are essential tools for proper and effective protection resulting in prioritisation of protection (Moilanen et al. 2005; Moilanen 2007; Janík and Romportl 2023).

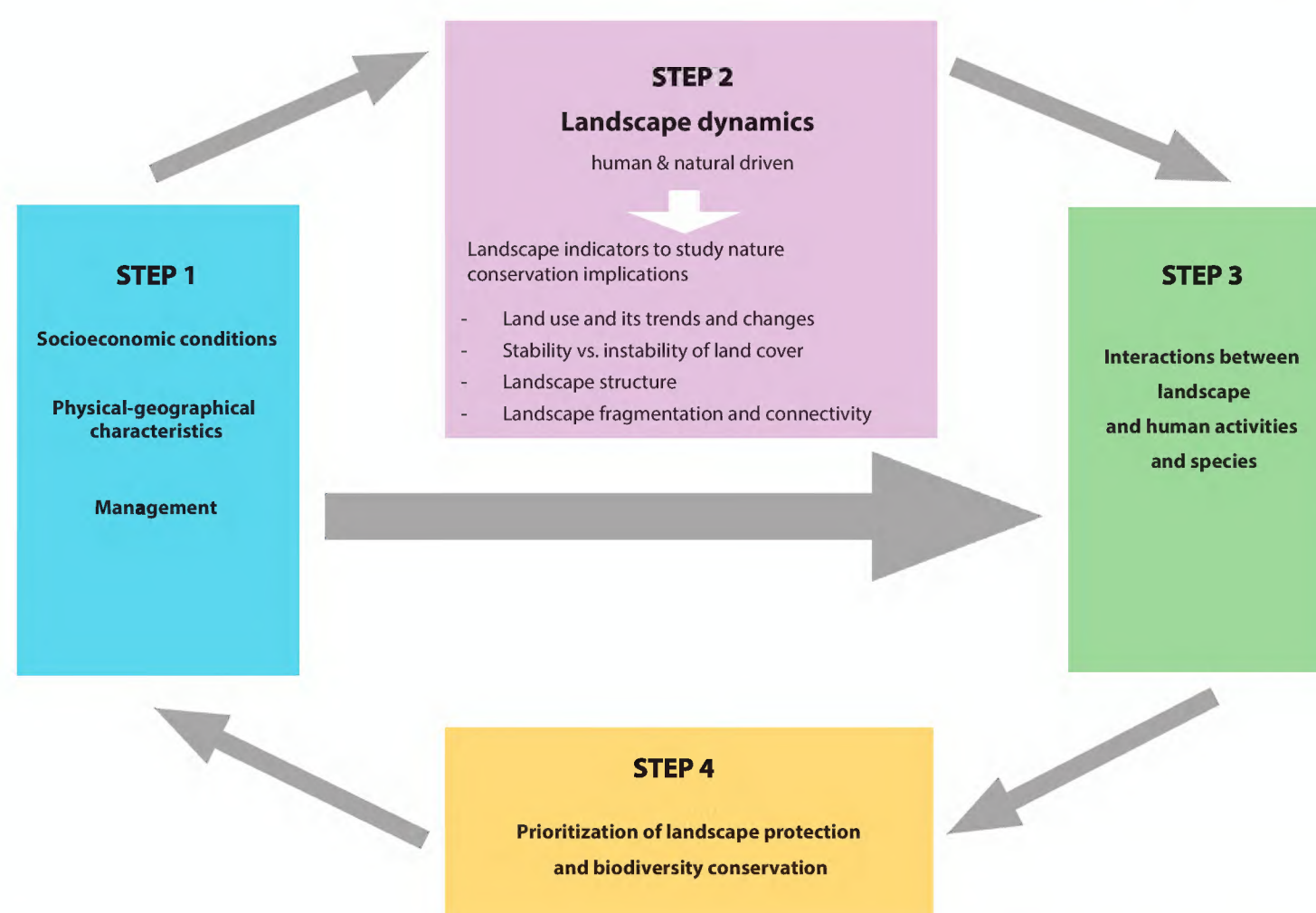


Figure 1. Diagram of relationships between steps within proposed LEP approach: The first step in our LEP approach is a blue part; conditions of the area influencing each other. Conditions as management, physical-geographical framework and human activities influence the second step (purple part, landscape dynamics). Blue and purple parts are inputs for interaction between landscape, human and species. This third step (green) consists of modelling biodiversity (habitat suitability models). All three steps together are inputs for synthesis – a yellow fourth step for prioritisation regarding the protected areas. It, again, influences management of the area and starts another circle of processes.

Table 1. Steps of the LEP approach and how they were used regarding ŠNP.

Steps	Used LEP	Used data	Used methods	Solved concerns	Integration with other steps	References (regarding ŠNP)
Step 1: study area conditions	Landscape function	Physical-geographical characteristics (topography and climate) Socioeconomic data (inhabitants, visitors, GDP) Management of the PA	Typology Literature and data review and comparison	SWOT analysis of the PA Differentiation of the PA (within the area and also with neighbourhood) Management	Inputs:	Janík and Romportl 2016; Janík and Romportl 2017; Janík 2020
					• information on typology of the areas	
					• management of the area	
					• wildlife management	
					• use of the area by human (recreation)	
					Outputs:	
					• typology of PA • human use of the PA	
Step 2: landscape dynamics	Landscape structure Land cover changes	Land cover data	Land cover change analysis	Land cover change and stability facing natural disturbances and anthropogenic activities	Inputs:	Janík and Romportl 2018; Janík et al. 2019; Janík et al. 2022; Křenová et al. 2022
					• typology of PA • human use of the PA	
					Outputs:	
					• stability of the land cover • naturalness of land cover	
Step 3: protecting species and enhancing biodiversity	Landscape function Landscape structure	Environmental variables Anthropogenic structures Occurrence data	Habitat suitability modelling	Detection of valuable habitats for selected species	Inputs:	Janík et al. 2021b; Bluhm et al. 2023
					• land cover data (stability, naturalness)	
					Outputs:	
					• habitat suitability models • anthropogenic risks for biodiversity (e.g. landscape fragmentation)	
Step 4: landscape ecology in practise	Integration of all these steps	Land cover data Habitat suitability models Anthropogenic structures Management and zonation of the PA	Synthesis of data from previous steps (land cover, habitat suitability models) Prioritisation software (e.g. ZONATION)	Synthesis of previous steps and prioritisation of nature protection, comparison with current state	Inputs:	Janík and Romportl 2023
					• land cover data	
					• habitat suitability models	
					• human use of the PA	
					Outputs:	
					• prioritisation • comparison to management of the area from step 1	

All four steps, further in this chapter, are described generally in detail and in the Results chapter as a case study from our model area. These steps are imprinted to nature protection and management of PAs. We propose integrating all these perspectives, bridge the gap between science and practical conservation (Müller and Opgenoorth 2014), and support evidence-based conservation (Sutherland et al. 2004).

Case study area

Šumava National Park was established in 1991, after the fall of communism, in the south-western part of Czechia. ŠNP was demarcated within Šumava Protected Landscape Area (ŠPLA), which now creates the surroundings of ŠNP (Janík and Romportl 2018). ŠNP covers 683.4 km² and it is almost three times larger than its German neighbour – Bavarian Forest National Park (BFNP) (Fig. 2). Formerly, ŠNP was divided into three conservation zones.

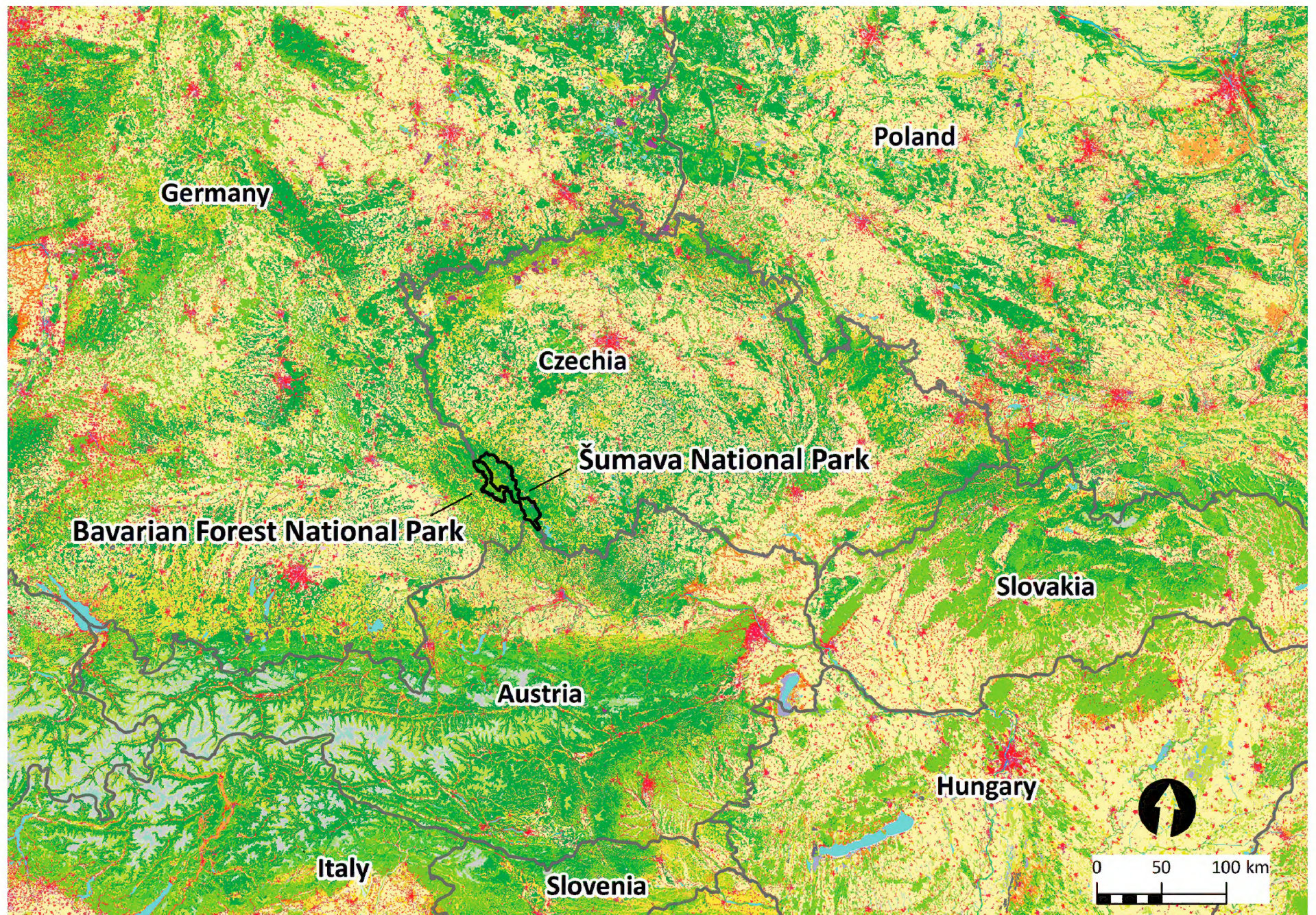


Figure 2. Case study area; Šumava and Bavarian Forest NPs in Central European landscape. Data sources: Corine Land Cover (European Environment Agency), Open Street map.

The first zone was the most protected; it covered 22% in 1991 and it even shrank to 13% in 1995 (Křenová and Hruška 2012). Large fragmentation of this strictly protected area, together with different forest management applied in different zones (including large-scale logging during the bark beetle outbreak), negatively affected ecosystems in ŠNP (Šantrůčková et al. 2010; Křenová and Hruška 2012). Therefore, these management steps led to the concerning interest of scientists and conservationists in the further development of ŠNP.

Scientists criticised these changes of zonation and forest management (Křenová and Kindlmann 2015; Zýval et al. 2016) and delivered a proposal of zonation based on mapping of habitats and species for the NATURA 2000 sites network: an easy-to-make proposal was made using an overlay of key layers (valuable habitats, core areas of capercaillie (*Tetrao urogallus* - the umbrella species)); the proposal delimited 51.9% of the area of ŠNP for the most valuable first zone (Bláha et al. 2013); however, this proposal has not been accepted. Based on an amendment of the Czech Nature Conservation Act, a new zonation with four zones came into force in 2020. A natural zone, the most strictly protected one with non-intervention management, currently covers 27.7% of ŠNP. Nevertheless, there are still some shortcomings regarding management of valuable habitats, especially in forests (Křenová et al. 2022). In the context

of these turbulent changes, we systematically and continually focused on the research of landscape protection and nature conservation in ŠNP, as it is an interesting study site and a suitable laboratory for our approach.

Step 1: Study area conditions

To understand processes within a certain area, it is necessary to know how its geographical and environmental conditions vary in space. Therefore, GIS software enables using objective data and deploys analysis of abiotic environment or/and landscape parameters resulting in a typology of a study area from one (and a small) PA to national or even continental or worldwide scale, and helps to understand differences within the landscape on various scales (Chuman and Romportl 2010; Romportl et al. 2013). Based on the results of such a typology, we can see the study area through separate landscape types.

Moreover, other drivers of PA management are economic and social conditions. After abiotic and landscape conditions, which can be investigated through typology like our frameworks, anthropogenic presence and management is the next layer. PAs can be beneficial for the local community and can bring economic activities, such as tourism (Brown et al. 2015; Yakusheva 2019).

Step 2: Landscape dynamics

The above-mentioned abiotic conditions and anthropogenic activities imply characteristics of landscape changes that are crucial for ecosystem services and biodiversity (Feranec et al. 2010; Tappeiner et al. 2021). Value of the landscape and its change for protection was studied, e.g. by Němec et al. (2022). Basically, these indicators are recognised as important:

- Land use and its trends and changes
- Stability versus instability of land cover
- Landscape structure
- Landscape fragmentation and connectivity

Information on history, regarding nature protection, stability and instability, persistence and change of the landscape, from a temporal-historical view are a key for biodiversity conservation and nature protection (Guerra et al. 2019; Němec et al. 2022). Moreover, history can help to manage sustainability of the landscape for the future (Tappeiner et al. 2021). Long-term legacies of changes affect fauna and flora (Turner 2010).

The stability of natural development is crucial for biodiversity, however, in some parts of the area, the main value of landscape to protect can be heterogeneity of landscape structure (e.g., caused by natural disturbances) supporting biodiversity (Turner 1989; Bengtsson et al. 2003; Turner 2010; Janík et al. 2021a), even after windstorms and bark beetle outbreaks in the study area (Thorn et al. 2017).

Based on our results and literature review, this step should specify main drivers and types of landscape change regarding the conservation concern.

Step 3: Protecting species and enhancing biodiversity

Generally, mapping biodiversity is a proper and effective conservation tool and it is an inherent part of management of spatial nature protection (Margules and Pressey 2000). Linking knowledge about occurrence of species and habitats with information about quality of the landscape and environmental conditions significantly improves conservation knowledge. More detailed environmental variables, based on environmental and landscape evaluation from previous steps, can be analysed as predictors for suitability of habitats for certain species and occurrence of certain habitats. Data about species and habitat occurrence can be used to model potential distributions of target species (Phillips et al. 2006; Elith et al. 2011). Spatial distribution of habitats can be modelled as well (Mücher et al. 2009). This is especially suitable for larger areas for which we have less knowledge about habitats.

In addition to models, there is a necessity to evaluate anthropogenic activities and pressure negatively affecting dispersal of animals, which were gathered in the first step. Fragmentation of landscape and connectivity is, therefore, another topic of landscape ecology with practical impacts on spatial nature protection (Turner 1989). While fragmentation can lead to isolation of populations with many negative consequences or, on the other hand, to a more heterogeneous landscape, connectivity is needed and it can prevent the population from extinction (Tscharntke et al. 2012).

Step 4: Landscape ecology in practise

The last step of this proposed concept of LEP used for landscape protection is to integrate all the previous steps and give recommendations to PAs administrations on how to manage their area in the most appropriate way. By using both species and ecosystem data, with local knowledge on values and qualities for protection and threats and costs to consider, we can maximise the benefit for effective spatial protection prioritisation (Ceașu et al. 2015).

Fortunately, a prioritisation bringing complexity can consider nature protection as well as other activities within a target area to delimit appropriate land-use management (Bekessy et al. 2012). In this study, by using LEP concept and software ZONATION (Moilanen et al. 2005; Moilanen and Kujala 2006) in this last step 4, all relevant objectives including social, local and recreational, are also met (Moilanen et al. 2011; Watson et al. 2014). ZONATION works as a spatial conservation tool using hierarchical prioritisation as it iteratively removes cells of the data inputs (raster layers) (Moilanen 2007). Inputs could be data such as biodiversity features, qualities of the landscape, anthropogenic pressures (habitat suitability maps, biotope quality maps, anthropogenic transformation of the landscape). This concept can be used with various data and in various tasks; as well as in different geographical locations or scales (e.g., Rayfield et al. 2009; Carroll et al. 2010; Leathwick et al. 2010; Sirkiä et al. 2012; Srivathsa et al. 2023).

Results

For an unquestionable clarification of the presented concept and a better illustration of its use in PA management, in this chapter we present experiences with the implementation of this concept in the Šumava National Park.

Step 1: Case study area conditions

Typology of ŠNP and neighbouring BFNP was created using topography and climate data. It shows several different physical landscapes in the study area (Janík and Romportl 2016, see Fig. 3). There is a difference between the flatted core area of the upper mountain plateau along the borderline and subsequent steep parts and those with lower altitudes, in particular. This internal differentiation of the study area enables further investigation, for example for evaluation of forestry changes after disturbances (Křenová et al. 2022).

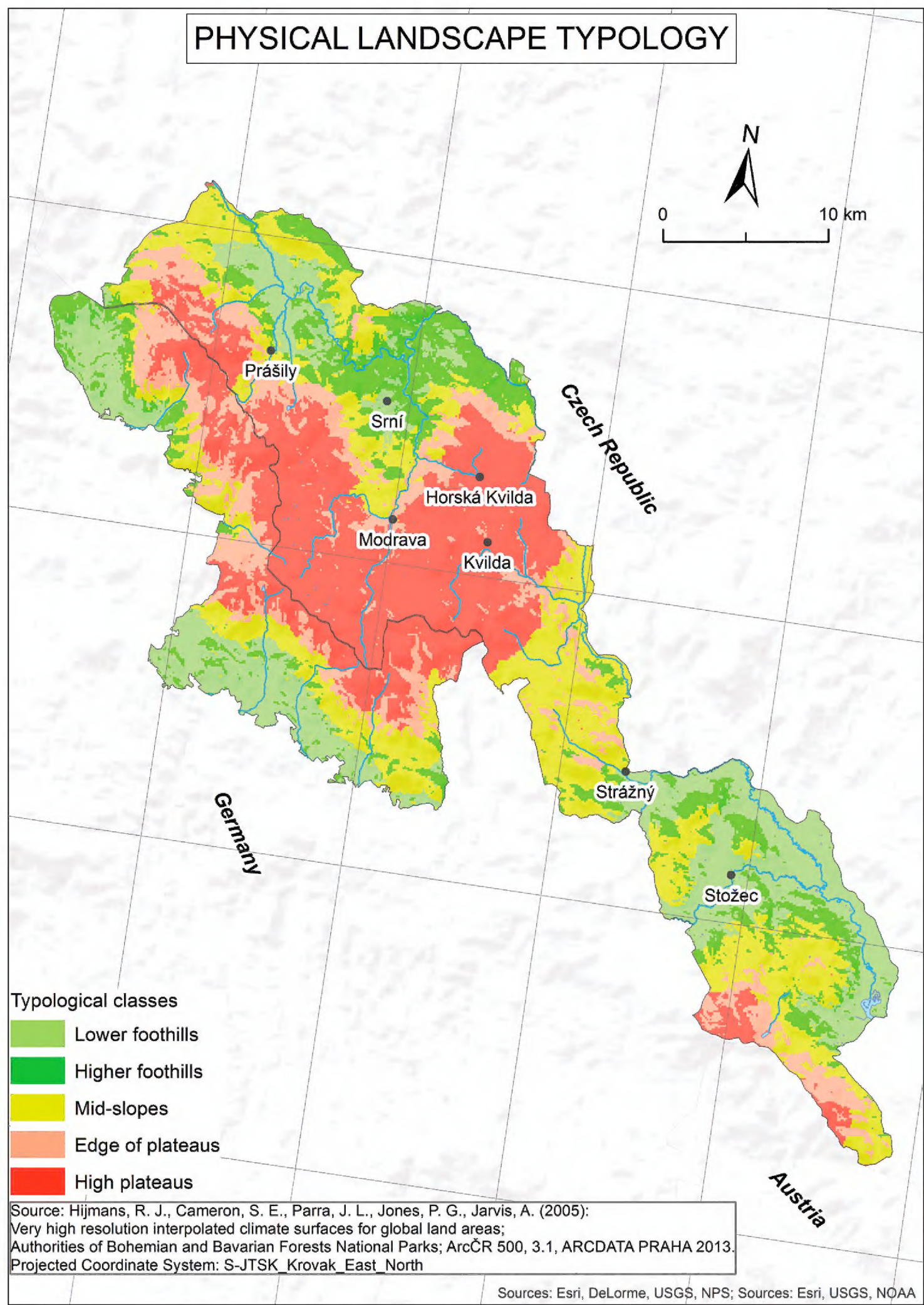


Figure 3. Landscape typology of Šumava and Bavarian Forest NPs (Janík and Romportl 2016).

ŠNP and BFNP, a transboundary area with two national parks, is a very suitable site for investigation of this layer. These two NPs share the same ecosystems, key species, and very similar conservation targets (Křenová and Kiener 2012). However, the historical development and path dependency of management, economy, and society differ; mainly in the period after World War II, political decisions resulted in a discontinuity of settlement, access restriction, and delay in upgrading the protection status of ŠNP on the Czech side (Janík and Romportl 2017; Janík 2020). Therefore, history led to different institutional environment, management, and nature protection between countries (Brown et al. 2015; Křenová and Kindlmann 2018). This is particularly evident in the Czech and German parts of the area, especially concerning wildlife management, management and zonation of the national parks with a lower level of protection in ŠNP (Janík 2020). Since the 1990s, following the transition to democracy and capitalism in Czechia, varying perceptions of ŠNP management among key stakeholders have persisted, leading to disagreements regarding the management and development of the area on the Czech side (Brandon and Wells 1992; Janík and Romportl 2017). It is also given by mixed ownership in ŠNP, which makes the management even more challenging. However, in case of transboundary harmonisation, coordination has improved, e.g. enlarging of a zone with strict non-hunting area regarding wildlife management (Janík 2020). From an economic perspective, tourism has been recognized as a significant part of the economy for BFNP and its profit is higher than from the potential timber industry (Mayer and Job 2008). The results of the similar study for ŠNP have not been published yet (Harmáčková et al. 2016). However, the Czech NP also yields significant economic benefits for the region, which could be further enhanced if tourists extended their stays (Dickie et al. 2014; Bílá et al. 2019). ŠNP is three-times larger, includes the settlements and also the number of visitors is higher than in BFNP; estimations are 760,000 for BFNP and 2,000,000 for ŠNP annually (Mayer and Job 2008; Perlín and Bičík 2010). Therefore, we identify main the anthropogenic structures such as built-up areas and recreational zones to characterise human activities.

Using this detailed knowledge on the specific PA (here ŠNP), its attributes, qualities, and values, as well as the threats and costs, can be determined for further steps (Kujala et al. 2018).

Step 2: Landscape dynamics

General trends show extensification and abandonment of agricultural activities in peripheral mountainous regions, coupled with forest growth across Europe and in Central Europe and Czechia as well (Latocha 2009; Kupková et al. 2013; Kupková and Bičík 2016; Ameztegui et al. 2021). The abandonment contributes to the ecological stability (Guerra et al. 2019) of the landscape but could threaten biodiversity by reducing habitat diversity in agricultural landscapes (Queiroz et al. 2014; Zakkak et al. 2015). On the other hand, land use of part of the mountainous regions, including ŠNP, is being intensified, for example by recreational activities (Verburg et al. 2009; Janík et al. 2019). These long-term (decades) changes of the landscape were caused predominantly by human-induced driving forces (political, economic and social processes) (Kupková et al. 2013).

In the case of ŠNP, a clear trend of land use extensification is evident, with agricultural practices shifting from intensive, such as arable land, to more extensive forms like permanent grassland, pastures, and meadows, resulting in an increase in forest cover (Janík et al. 2019, 2022). In ŠNP, the forest has remained stable over time roughly since protection was established (Janík et al. 2019). Regarding BFNP and ŠNP, this stable area can host species requiring large suitable habitats, such as large carnivores like wolves (*Canis lupus*) and lynx (*Lynx lynx*) and herbivores like moose (*Alces alces*), and it also leads to higher quality of habitats (Müller et al. 2014; Janík et al. 2021b; Bluhm et al. 2023).

However, in the geographical context of ŠNP, as one the largest Central European relatively natural and forested area, we can analyse also the dynamics after disturbance and subsequent natural and anthropogenic reactions (Dale et al. 2001; Bengtsson et al. 2003; Turner 2005; Turner 2010). In the forests of ŠNP, and similar natural mountainous forests, disturbances are an inherent part of their dynamics (Fischer et al. 2002; Grodzki et al. 2006; Heurich 2009; Brůna et al. 2013; Čada et al. 2013; Nováková and Edwards-Jonášová 2015). Forests in the case of ŠNP are able to regenerate (Brůna et al. 2013; Červenka et al. 2014; Janda et al. 2014). However, also human-induced interventions, such as logging or new clear-cuts were made in the vicinity of the area, which was affected by bark beetle infestation after the wind disturbance. It is a consequence of disagreement of main actors on future development of the area leading to its suboptimal management (Janík and Romportl 2018, see Fig. 4).

The second step provided us with data on landscape and its change as a key information for understanding ecosystems and their dynamics. In NPŠ, forest dynamics is primarily driven by natural disturbance. But human intervention, such as management practices, still plays a significant role, varying according to ownership (Křenová et al. 2022). It is also different in various geographical conditions according to framework originated in typology from the first step (Janík and Romportl 2016; Křenová et al. 2022).

Step 3: Protecting species and enhancing biodiversity

In the case of ŠNP, there are suitable habitats for some species. Therefore, we selected fifty key species and developed habitat suitability models as inputs for the fourth step to capture priority areas of their occurrence (Janík and Romportl 2023).

The region of our study and its core area of BFNP and ŠNP is a significant area for harbouring large mammals, because migration from the source population is impossible due to surroundings of the ŠNP with open cultural and inhabited landscape (Bluhm et al. 2023).

The suitability of this area for these species is high due to the presence of large forested areas and lower anthropogenic pressure (Anděl et al. 2010). Recently, a more detailed suitability analysis for moose (*Alces alces*) was assessed and published. It demonstrates that there is a suitable habitat for moose in ŠNP, yet the population has decreased (Janík et al. 2021b, see Fig. 5). Similar above-mentioned suitability maps were used as an indicator for suitability and consequence for protection of biodiversity.

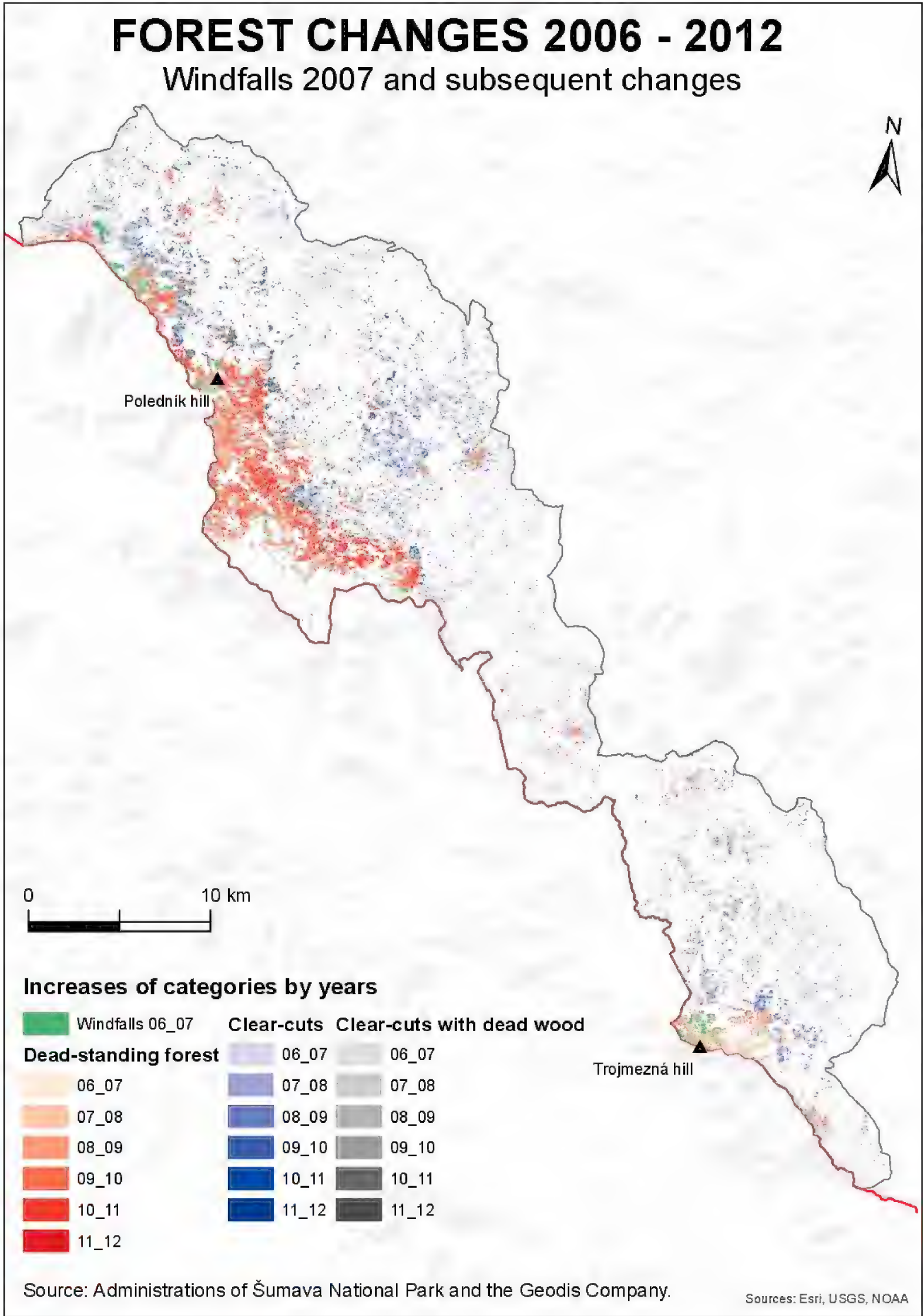


Figure 4. Forest changes 2006–2012 in Šumava NP (Janík and Romportl 2018).

Mapping anthropogenic activities and fragmentation of landscape by anthropogenic structures is another task crucial for preserving viable populations of target species regarding fragmentation of population or additional mortality. From this point of view, illegal hunting and wildlife-vehicle collisions pose serious threats to the lynx and moose populations in BFNP and ŠNP (Heurich et al. 2018; Janík et al. 2021b).

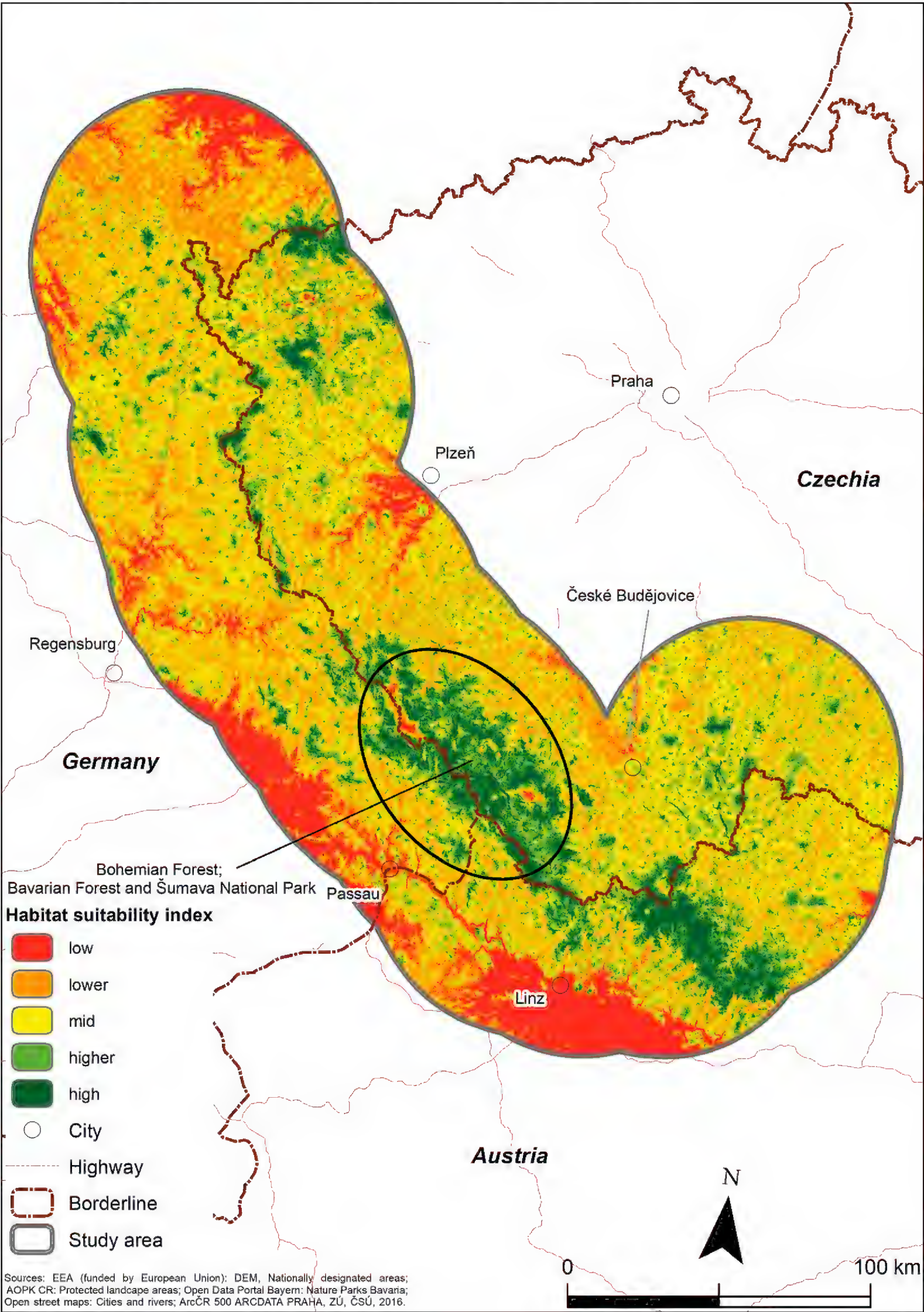


Figure 5. Habitat suitability index for moose (*Alces alces*) within the Bohemian Forest Ecosystem (Janík et al. 2021b).

Step 4: Landscape ecology in practise

In a case of ŠNP, after comprehensive analyses and based on knowledge and results from previous steps: 1a) typology (Janík and Romportl 2016), 1b) anthropogenic activities (Janík and Romportl 2017; Janík 2020), 2) analysis on landscape dynamics (Janík and Romportl 2018; Janík et al. 2019, 2022), 3) evaluation of

habitat suitability for key species (Janík et al. 2021b), a synthesis of the three above-mentioned levels was prepared. Specifically, the NATURA 2000 habitat mapping layers (*in sensu* Chytrý et al. 2010) with detailed resolution and information on habitat quality and stability during the last circa 15 years and habitat suitability models for selected key fifty species were the main inputs used to create prioritisation of landscape protection (Janík and Romportl 2023).

However, in the geographical reality of Central Europe, with high human population density, human activities and social and economic interests must also be included into consideration (Brown et al. 2015). By balancing these parts, sustainability is a desired aim (Kušová et al. 2008). Therefore, in our case, built-up and recreational areas were placed in the prioritisation process and treated as areas used by humans.

The result shows a prioritisation map suitable for finding core areas for protection and also highlights the differences between the model and current management zonation of ŠNP. It can be used by the ŠNP administration as material for management of the PA to fill the gaps (Janík and Romportl 2023, see Fig. 6).

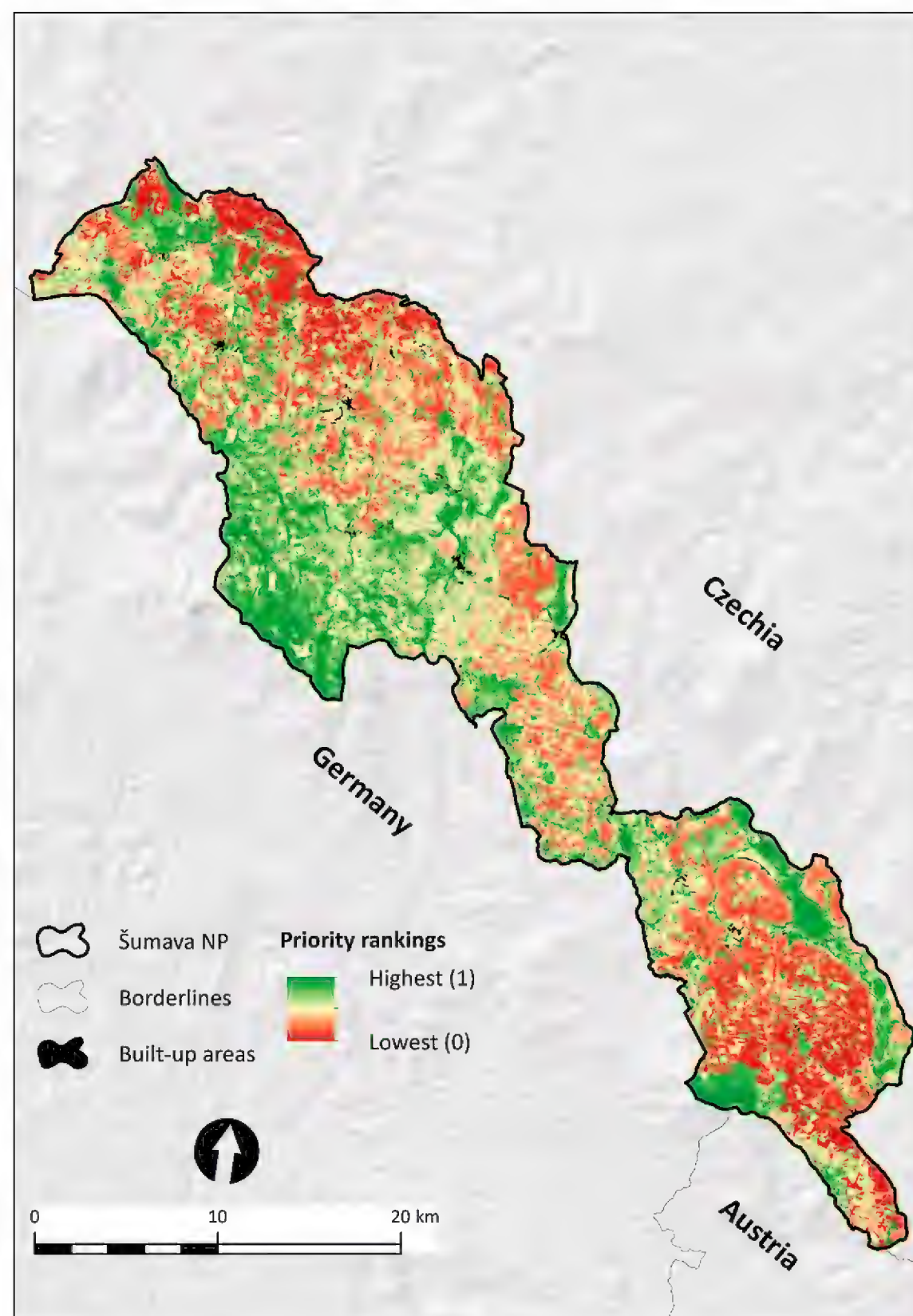


Figure 6. Prioritisation analysis of Šumava NP showing scale of priorities for protection from lowest (red) to highest (green) as a material for evaluation of NP's zonation (based on Janík and Romportl 2023).

Discussion

There is an urgent need to protect key areas for biodiversity, supporting ecosystem services and landscape functions, as well as human wellbeing (O'Connor et al. 2021). A proposed set of sequential steps, based on essential landscape ecological principles (LEP), can help to successfully address current conservation challenges. The concept presented in this paper offers new opportunities to expand methodological approaches so far used in geography and landscape ecology for nature conservation and to improve conservation management (Fig. 1).

We propose applying a comprehensive approach using LEP and producing a final output – a model for prioritisation of spatial nature protection goals in the area of interest.

Our LEP approach incorporates all relevant features for protected areas' planning and designation. In the first step, we dealt with society and its relationship to ecosystems and protection of the area (Müller and Opgenoorth 2014; Soliku and Schraml 2018; Janík and Romportl 2017; Janík 2020), step two analysed landscape and ecosystem data (Ceaşu et al. 2015, Janík and Romportl 2018; Janík et al. 2019), step three stressed biodiversity (selected species) as some other studies e.g. Sirkiä et al. 2012; Jenkins et al. 2015; McGowan et al. 2020.

Therefore, species and ecosystem data are used to cover relevant factors as much as possible (Ceaşu et al. 2015), and costs and constraints are balanced in a clear scheme. Finally, step four integrated previous steps and prioritised conservation of the PA (Lehtomäki and Moilanen 2013; Janík and Romportl 2023).

In the face of today's anthropogenic transformation, protected areas (PAs) hardly reach the spatial and temporal requirements for delimiting good quality PAs (Bengtsson et al. 2003), e.g. for some species with high spatial requirements, such as wolf (*Canis lupus*), lynx (*Lynx lynx*) or moose (*Alces alces*) in our case study, which are threatened by fragmentation and they need large-scale and connected landscape, thus detailed prioritisation is not crucial for them (Turner 2005; Heurich et al. 2018; Bluhm et al. 2023). Moreover, with other interests of stakeholders, the establishment of PAs is often a political, socio-economical, esthetical, or cultural-driven decision (Müller and Opgenoorth 2014; Soliku and Schraml 2018). Therefore, our approach can help to fulfil our worldwide targets from Aichi or Kunming-Montreal Global Biodiversity Framework using objective data and methods.

In addition, some activities, e.g. tourism and its intensity influencing negatively PAs, are hardly detectable (Verburg et al. 2009; Křenová and Kindlmann 2015). On the other hand, large-scale natural impacts (such as disturbance) can change regions of PAs rapidly but without being necessarily harmful, then to set an appropriate management is needed, however the decision to not intervene is an option as well (Turner 2005). In the Anthropocene setting and the context of Central Europe, we are facing negative influences of strong anthropogenic pressure on nature. However, using available high-quality data and the above-mentioned landscape ecological methods we may protect PAs more effectively and also find a sufficient solution for other valuable parts of the landscape and nature (Lehtomäki and Moilanen 2013).

Our proposed LEP approach can be widely used as a methodological framework in a diverse range of PAs, including NATURA 2000 sites, as well as in the

fulfilment of other European objectives, such as the Biodiversity Strategy (European Commission 2021).

Moreover, the process of prioritisation can be used in the process of new PAs designation, but also in the expansion or reorganisation of existing ones. In our case, it is a supportive material for the zonation of ŠNP. Zones differ according to their management and values (Janík and Romportl 2023). Elsewhere, harmonisation with other land use or future risks was considered (Schuster et al. 2023; Tamburini et al. 2023) or wider landscape planning and priorities (Srivathsa et al. 2023). However, our aim was to clearly wrap the methodical procedure and illustrate its usability in a well-mapped area (Janík and Romportl 2023). Of course, the use of this concept is not limited geographically or regionally. Depending on the availability of relevant input data, the whole process can be applied both in countries with a high level of nature conservation as well as in countries where nature and landscape protection is still developing.

Due to their complementarity and complexity, these steps can be used for a wide range of tasks and generally wherever around the World with various types of available data: from prioritisation and delimitation of new PAs (Bekessy et al. 2012) and setting priorities as supportive material for appropriate zonation (Janík and Romportl 2023), to management recommendations (Křenová et al. 2022; Bluhm et al. 2023). We therefore recommend that the conservation community use the whole set of proposed steps to strengthen the science-based approach to nature and landscape conservation.

Conclusion

This study shows a newly and clearly organised approach using landscape ecological principles to prioritise nature protection. We tested it on the largest national park in Czechia (ŠNP) as a pilot site. Despite the good database, we would like to improve our approach in the next steps, e.g. to use modern technology and more detailed data, which can capture anthropogenic pressures such as intensity of tourism or biotope structure. Our aim was to propose a scientific, evidence-based approach, based on objective data and – above all – not influenced by the subjective view of the author, one that was needed as a methodological framework for spatial designing and prioritising of PAs. We hope that such an approach, consisting of several steps described above, can help to manage PAs and protect nature with regard to all relevant factors.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization: DR, TJ. Data curation: TJ. Funding acquisition: DR. Methodology: TJ. Supervision: DR. Validation: ZK. Writing - original draft: TJ. Writing - review and editing: TJ, ZK, DR.

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Data availability

All of the data that support the findings of this study are available in the text and original articles cited in this paper.

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